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DISRUPTION OF 0°-LINE FLOW INDUCED BY
BARRICADE FRONTING A SIMULATED
EXPLOSIVES STORAGE MAGAZINE

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FEBRUARY 1991

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1. INTRODUCTION

High velocity jet flow exiting from shock tubes and underground munition storage site models was investigated by Kingery and Gion (1989) and by Zardas (1990). The jet flow creates stagnation pressures from four to seven times greater than the side-on overpressures along the 0° line in front of the tube. The peak side-on overpressure is used in the criterion for structural damage and quantity-distance (Q-D) relationships for the citing of various constructions. Thus, the greater loading effect from the jet flow suggests that the Q-D criteria should be revised, or, a method developed for interrupting this jet flow. The current U.S. Army Ballistic Research Laboratory (BRL) project has resulted, with funding from the Department of Defense Explosives Safety Board.

It is clear that an efficient method for disrupting the jet flow would be through the use of a barricade erected a short distance from the end of the tunnel. Recently, proposals have been made for large-scale Klotz Club tests (Vretblad 1988), in which a barricade fronting the explosives magazine tunnel may be used for one or more of the planned shots. The purpose of the barricade is to influence the blast dispersion and the debris and fragments ejected.

For the BRL 25.4-mm (1-in) shock tube facility, we have constructed a model barricade, scaled approximately 1:140 of the barricade of the proposed Klotz tests. The pressure measurements and the shadowgraph observation of the flow field beyond the barricade are the subject of the present report. The data reported here may offer some comparisons with the full-scale data when these are available.

2. EXPERIMENTAL SETUP AND PROCEDURES

2.1 Model Barricade. The model barricade is scaled about 1:140 of full scale, based on a 3.5-m equivalent diameter for the full-size tunnel opening. The dimensions, scaled up to the full-size barricade, are as shown in Figure 1. These may not be precisely those of the proposed barricade since revisions in the dimensions have occurred since the proposal date (Vretblad 1988). The model was constructed of hardwood and fastened to the groundplane (plywood platform) surface at a scaled distance of six meters, considered the minimum distance for access. The front face of the barricade was inlet to accept a flush-mounted pressure gage to read the face-on pressures.

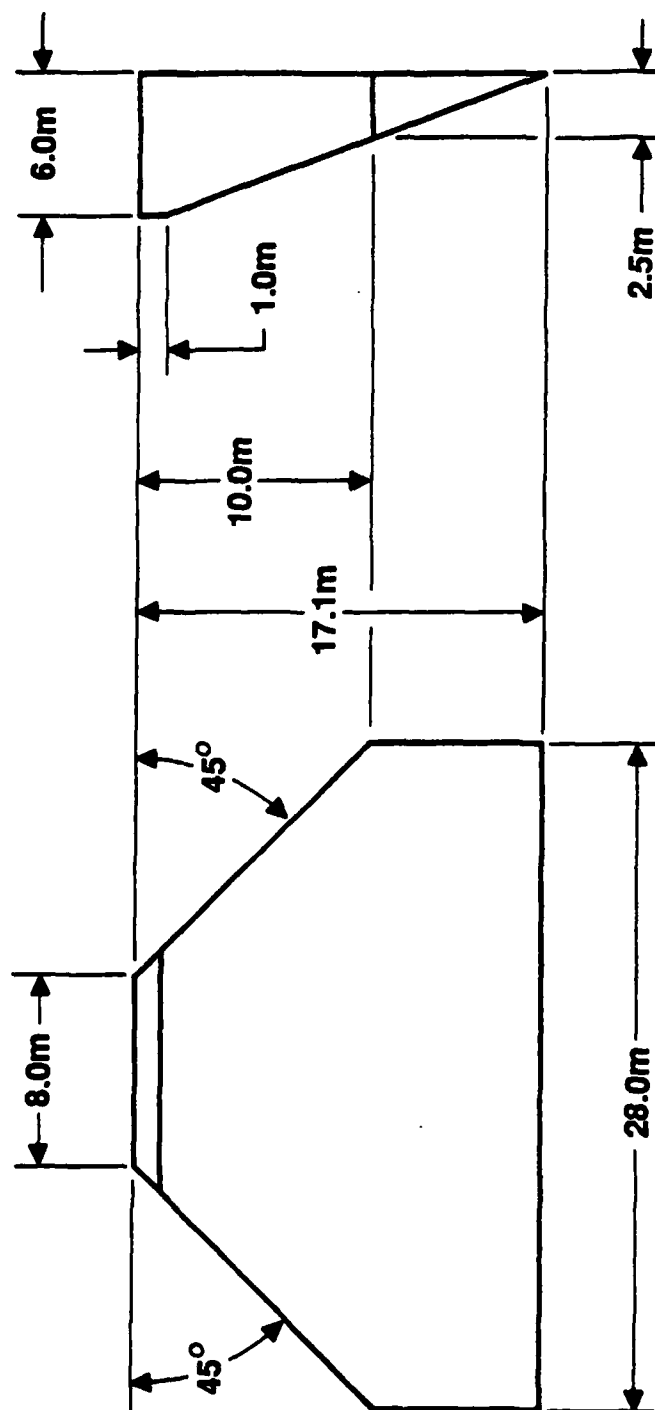


Figure 1. Model Barricade Scaled to Full Size.

2.2 Shock Tube and Test Site. The shock tube is the 25.4-mm (1-in) internal diameter (i.d.) shock tube used in the previous work for the free-field blast and jet effects from a simulated explosives storage magazine (Kingery and Gion 1989). The driver tube is 1.50 m long, and the driven tube is 1.33 m long. The tube is mounted onto a platform to facilitate instrumentation, which platform serves as the groundplane for the flow development. The cut sides of the mountain into which the full-scale tunnel is bored are simulated by two vertical boards coming off the tube exit and paralleling the sides of the barricade. The mountain sides rise vertically some 19+ m as scaled. The photograph of Figure 2a shows the tube exit from the mountain walls with gage stations along the 0° line. (A mounting board bringing pressure gages to height is not shown in the photographs). Figure 2b shows the filmholders in place for the shadowgraphs, while Figure 2c shows the barricade in place and gage stations.

2.3 Pressure Measurement. The data acquisition and reduction arrangement for the pressures is standard and is illustrated in Figure 3. Pressure transducers are piezoelectric type which may be flush-mounted in the ground plane, for the side-on measurements, or coupled to a Pitot probe configuration, for the stagnation pressure measurements. Only a single flow condition could be fired for this work, due to time and fiscal constraints. This condition was for an exit pressure (P_w) \approx 500 kPa. Shots at other conditions would be very useful.

2.4 Shadowgraphs. Shadowgraphs of the barricade's effect on the flow field were thought to be a useful complement to the pressure measurements to be made. Some shots were taken also without the barricade to see if the "mountain sides" noticeably affected the free-field blast and flow.

The shadowgraph setup is a simple one. A single spark source, a Hi Voltage Components, Inc., Model SS55P, was used. It illuminates three 20 x 25 cm (8 x 10-in) film and holders from an overhead position 1.09 m (42.5 in) above the ground plane. The spark source, with built-in power supply, is triggered by an Orthometrics Type 308b Time-Delay Unit, which receives the signal from the shock tube's exit pressure gage. Filmholders are placed beneath a protective glass sheet which now forms a portion of the ground plane. The glass sheet and holders may be shifted, if desired, to observe different portions of the flow field. For this work, only the 0° line was observed. From Kingery and Gion (1989), for $P_w \approx$ 500 kPa, the inhabited building distance is about 35 tunnel diameters from the tunnel exit. Thus, for such distances, it was sufficient to place the filmholders next to each other, straddling the 0° line, and next to the trailing edge of the barricade.

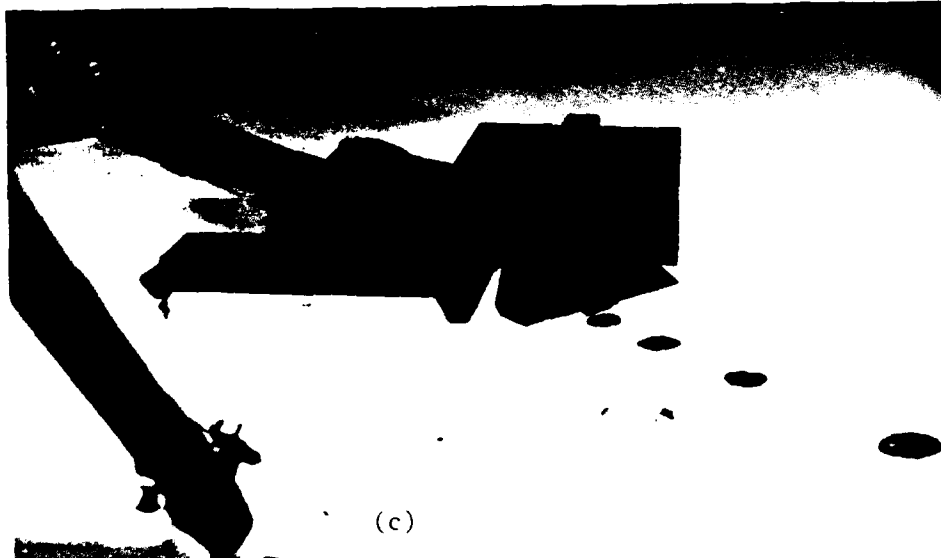
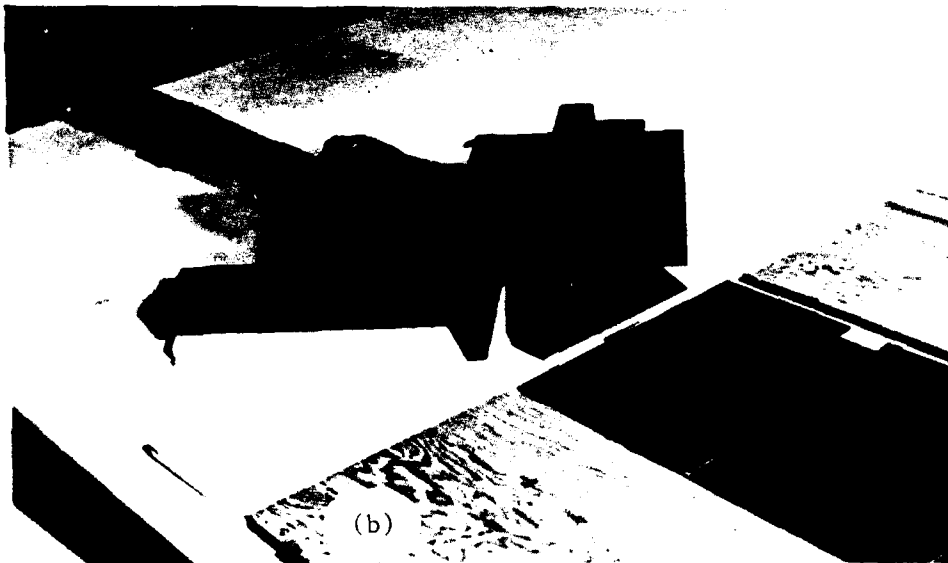
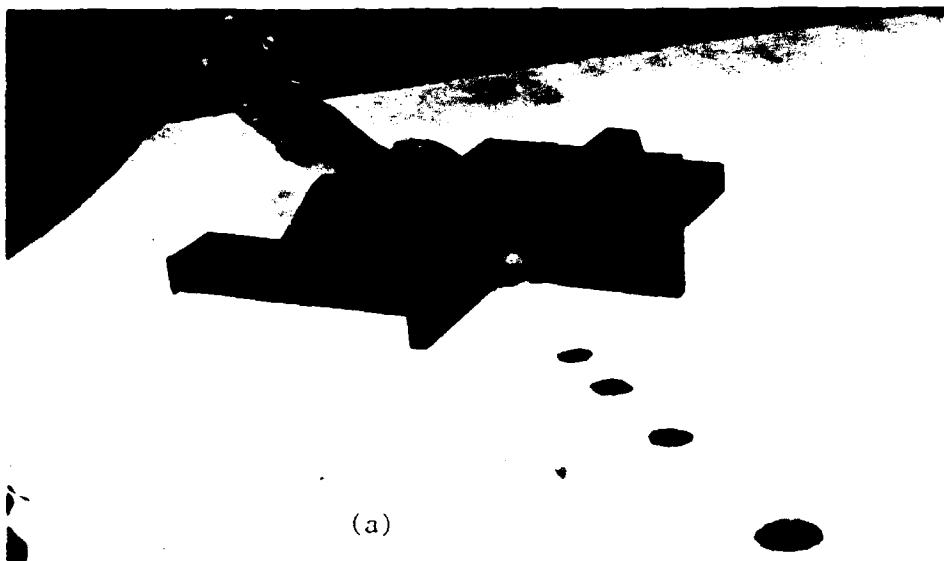


Figure 2. Photographs Depicting Shock Tube and Barricade. With Tube Opening From Simulated Mountain Side.

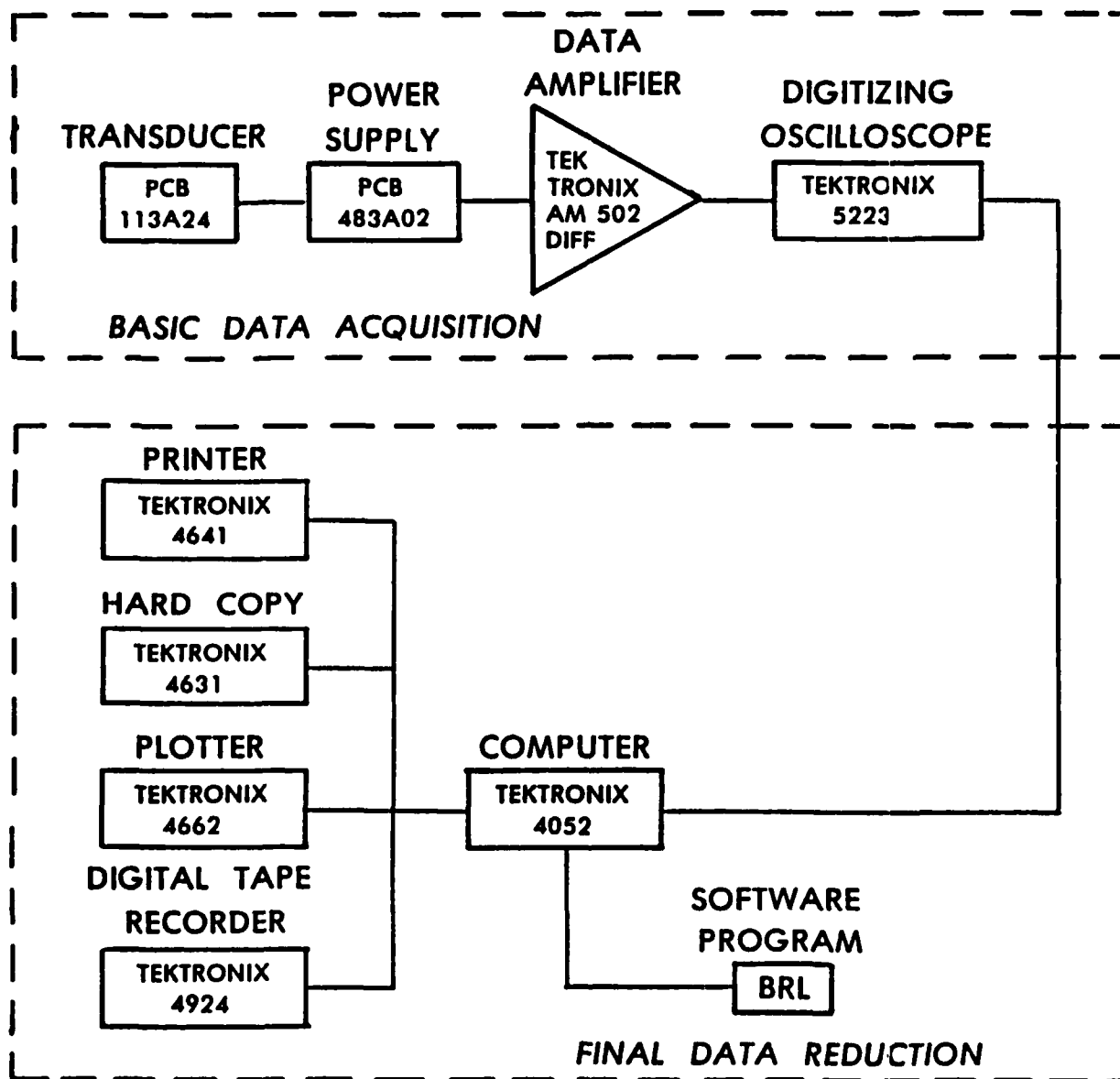


Figure 3. Data Acquisition and Reduction Scheme.

3. RESULTS

3.1 Shadowgraph Results. Figure 4a shows a set of shadowgraphs for the jet flow at 4.5 ms after tunnel exit. These films are for the tunnel without barricade (but with "mountain side"). The films for Figures 4a and 4b are not in true distance relationship to each other, as for a shot, but are juxtaposed to fit on the page. Figure 4b shows the result with barricade in place, at the same 4.5 ms after shock exit. Some pressure waves running in a generally forward direction are visible in film No. 3, whereas the jet flow has apparently disappeared from the 0°-line flow. A trace of the jet flow is yet visible at the top of film No. 1, or coming around the side of the barricade.

The arrival times of the forward edge of the jet, for the flow without barricade, are plotted in Figure 5. The points and curve from the free-field jet flow for the same flow condition, from Kingery and Gion (1989), are also shown. Apparently, the mountain side has no noticeable effect on the jet flow. However, some reinforcement of the free-air blast might be expected, but no separate measurements for such pressures were made.

3.2 Pressure Measurements.

3.2.1 Sample Pressure Traces. As mentioned, only one exit pressure level was fired due to time and fiscal constraints-- $P_w \approx 500$ kPa. Measurements were made along the 0° line at 10, 15, 23, and 35 D from the tube exit, the farthest distance being the "inhabited building distance" for this exit pressure level, with the side-on pressure ≈ 7 kPa (1 psi).

Sample side-on traces, for barricade in place, are shown in Figure 6a. For comparison, earlier free-field traces from the work of Kingery and Gion (1989) are shown in Figure 6b. Similarly, the stagnation pressure traces [which are approximately the dynamic pressures in the unbarricaded case (Kingery and Gion 1989)] are shown in Figure 7a for the barricaded situation and Figure 7b for the unbarricaded situation. The greatly enhanced stagnation pressure levels of the unbarricaded case, due to the jet flow over the stations, is very evident. And, the jet flow's absence, with barricade in place, is very clear. Moreover, absolute peak levels apparently have decreased somewhat from the unbarricaded case to the barricaded case. Figure 8a shows an example of the tube exit pressure trace, which is the reference condition for the exiting flow. Figure 8b shows a typical trace for the face-mounted gage in the barricade. At 1.72 D (scaled 6 m) from the exit, the reflected pressure is seen to be below P_w .

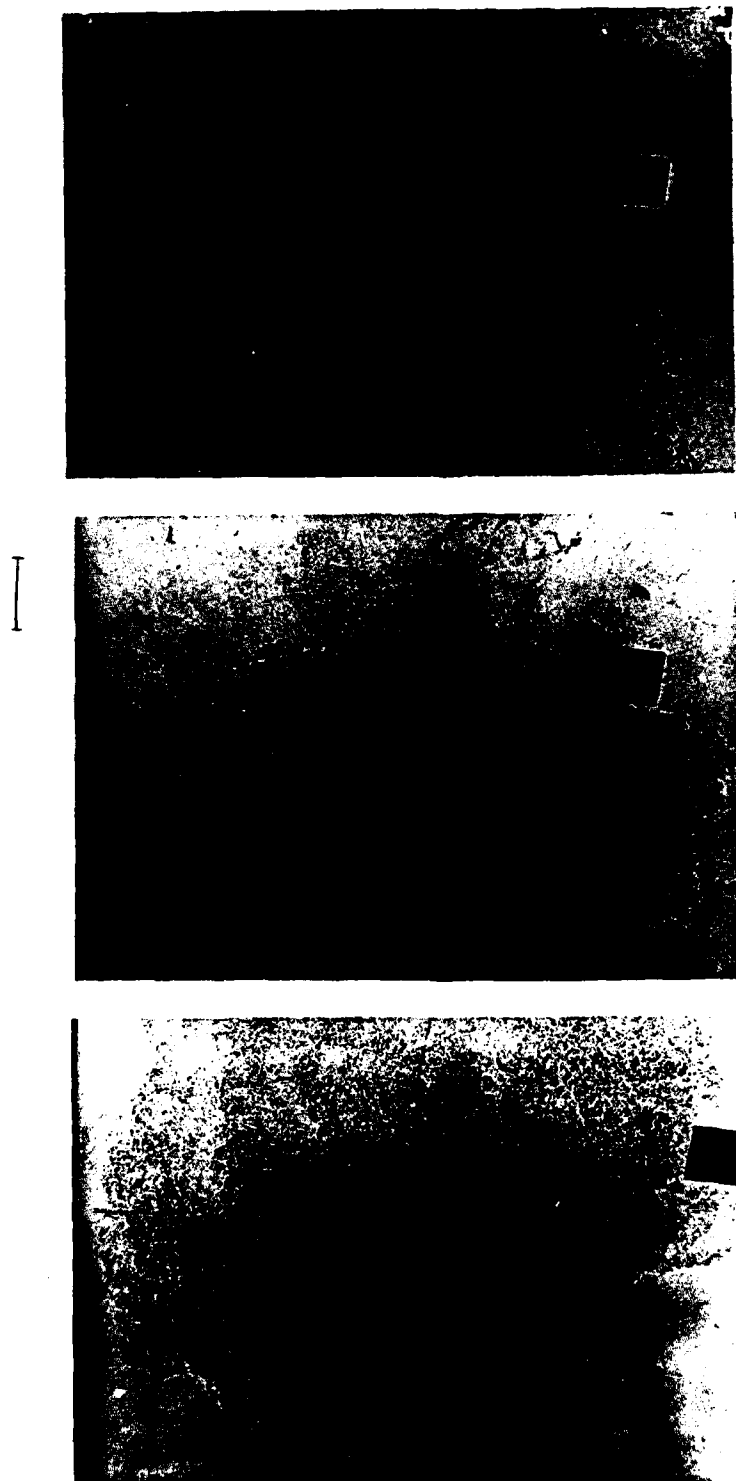


Figure 4a. Shadowgraphs of Flow Without Barricade.

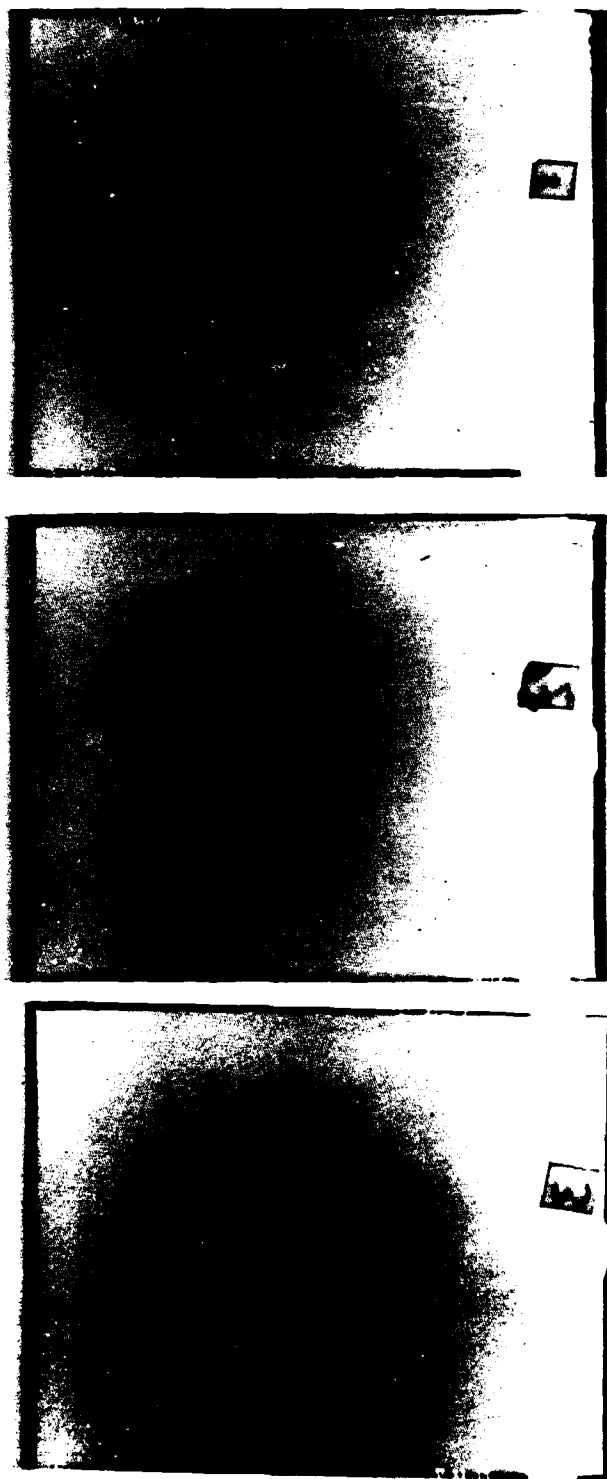


Figure 4b. Flow With Barricade in Place.

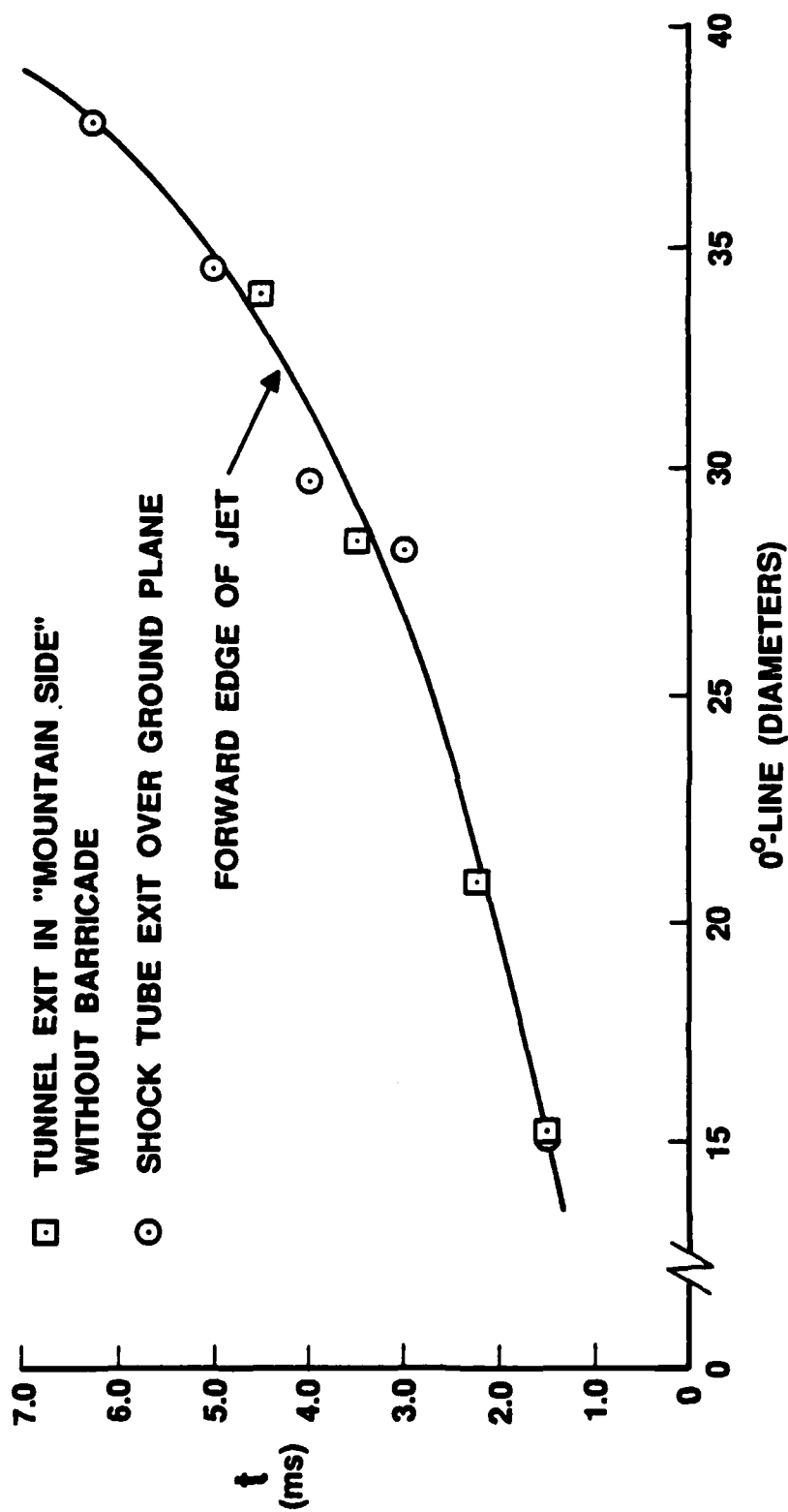


Figure 5. Jet Flow Motion.

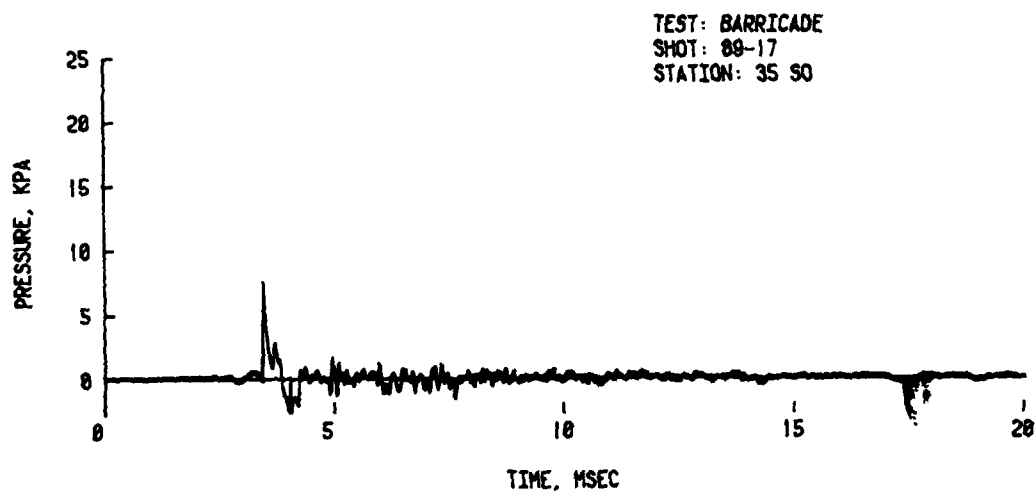
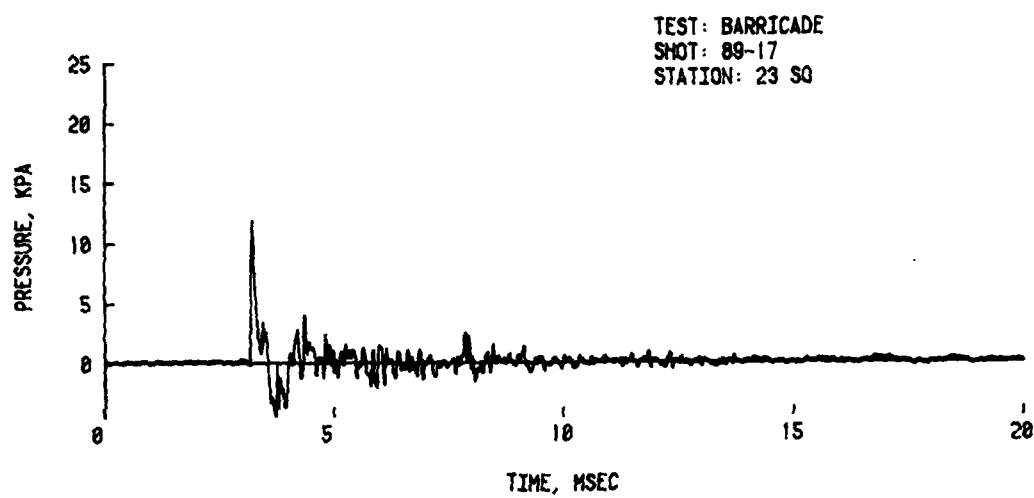
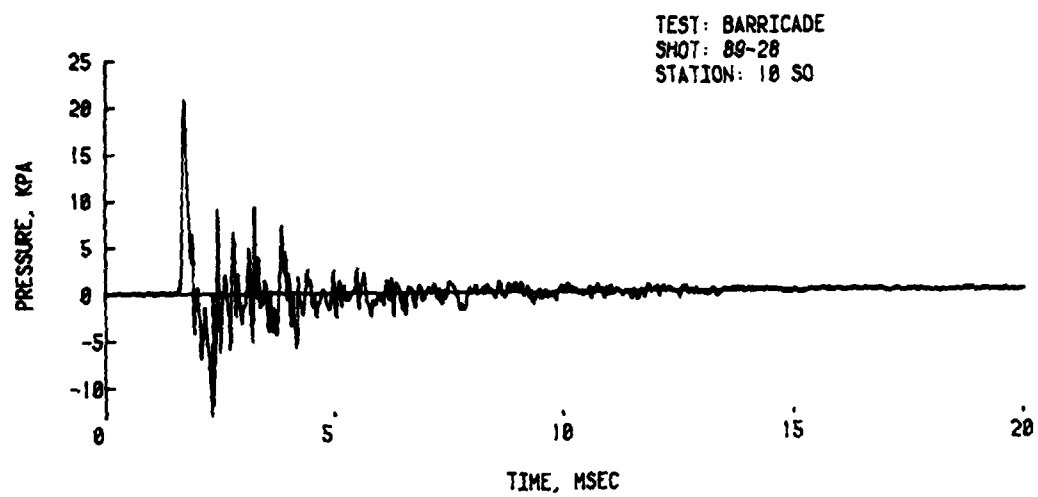


Figure 6a. Side-On Pressure Traces. With Barricade.

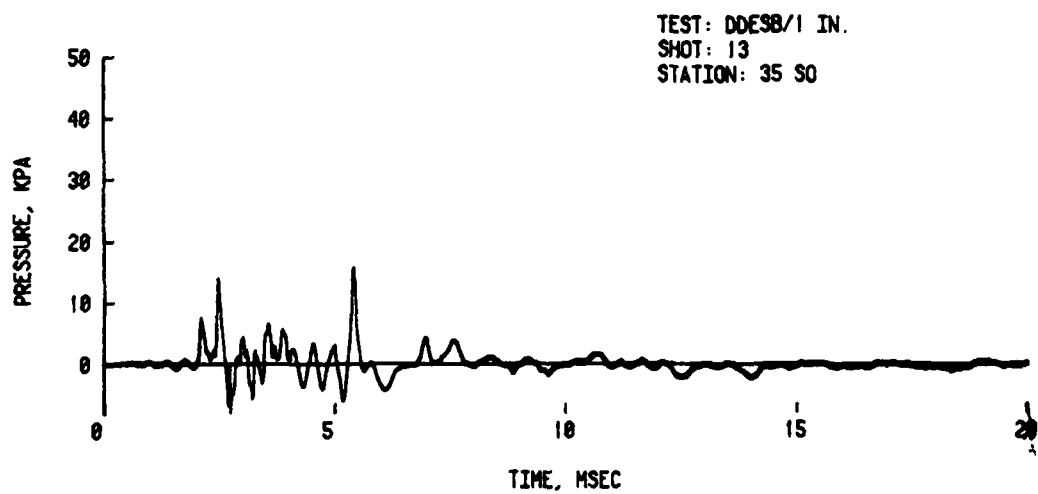
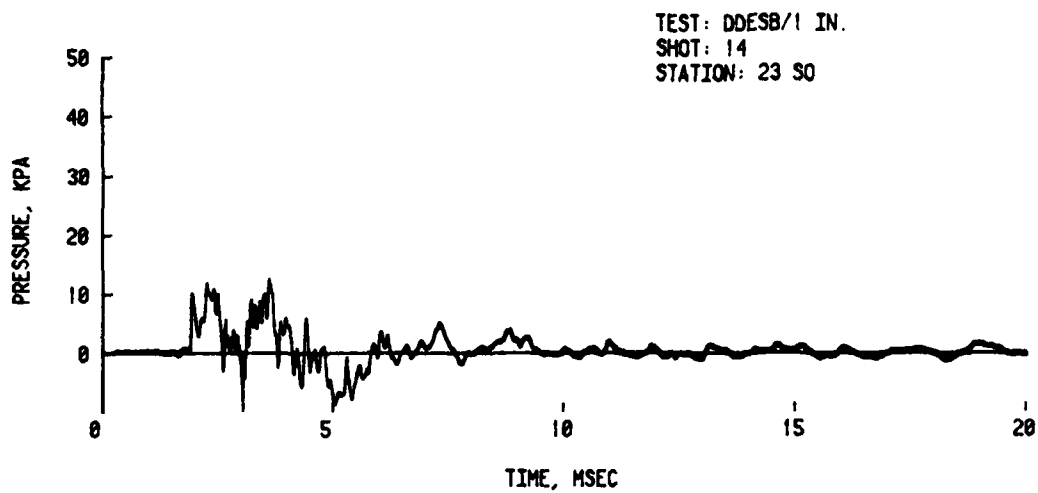
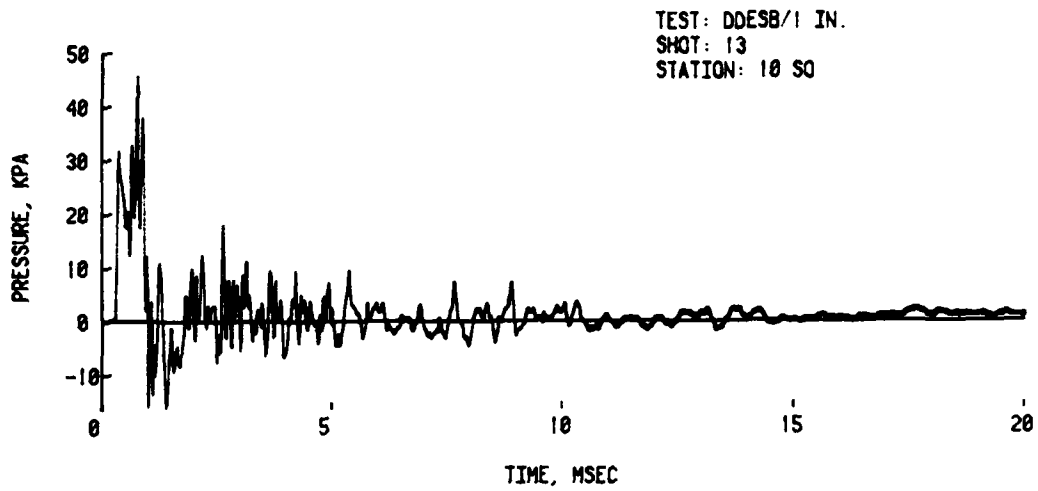


Figure 6b. Side-On Pressure Traces. Without Barricade.

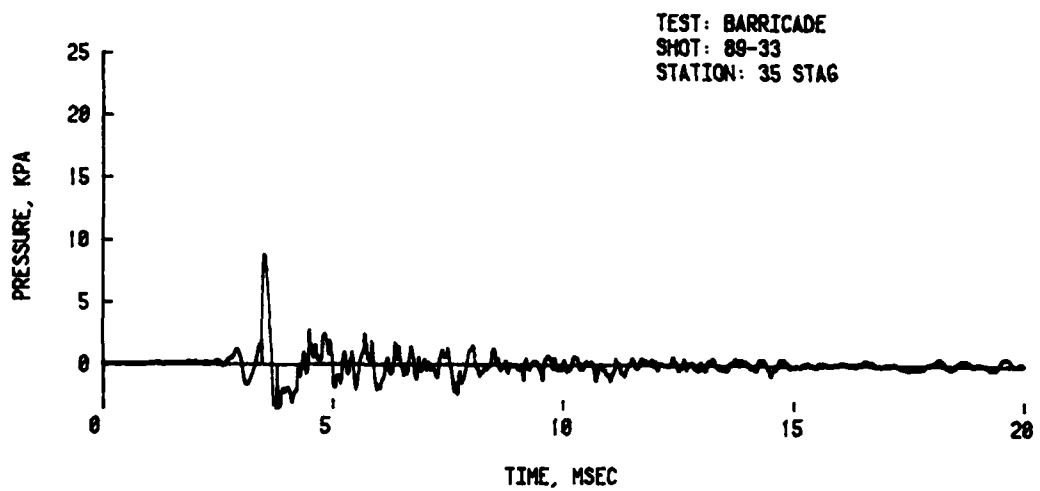
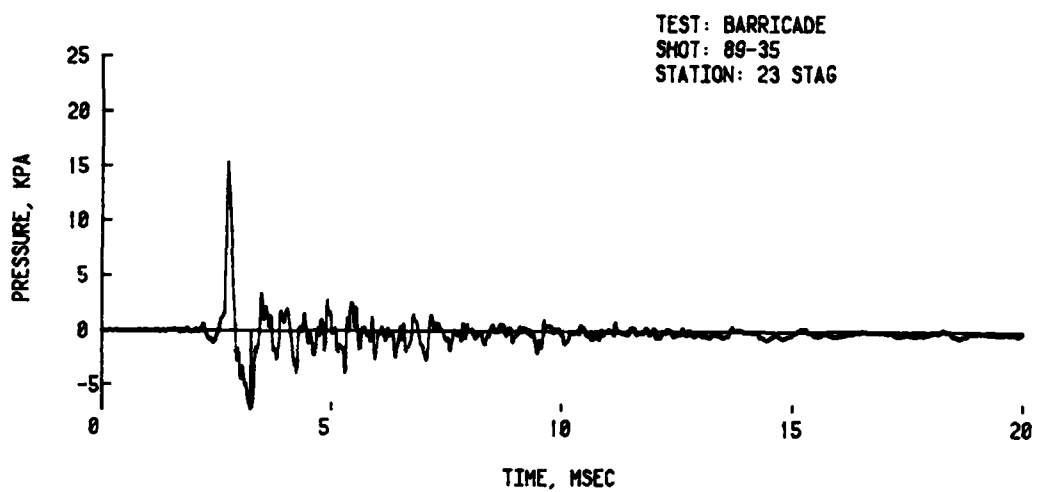
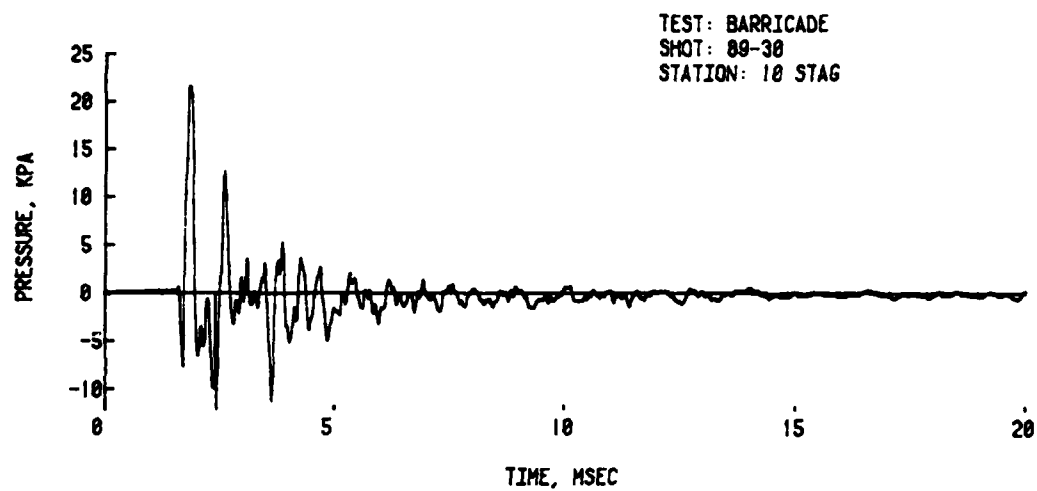


Figure 7a. Stagnation Pressure Traces. With Barricade.

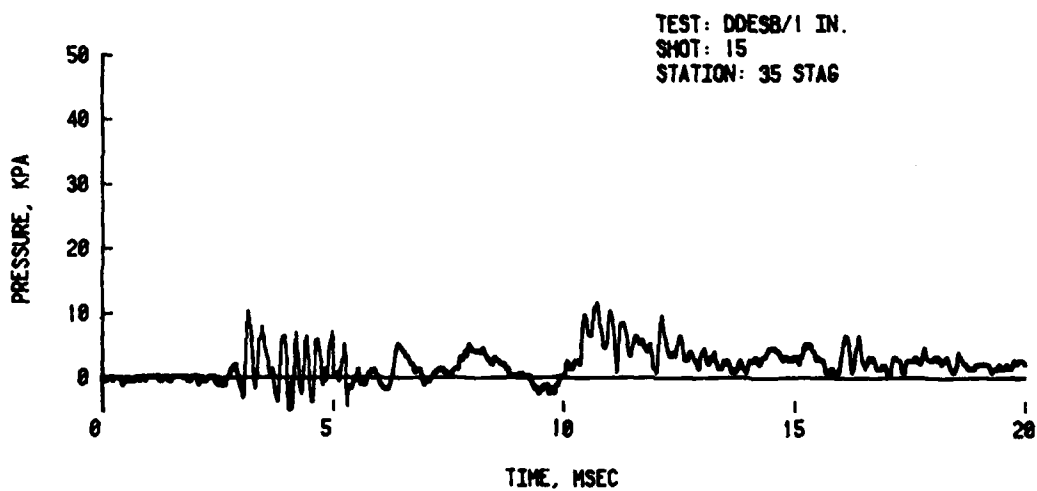
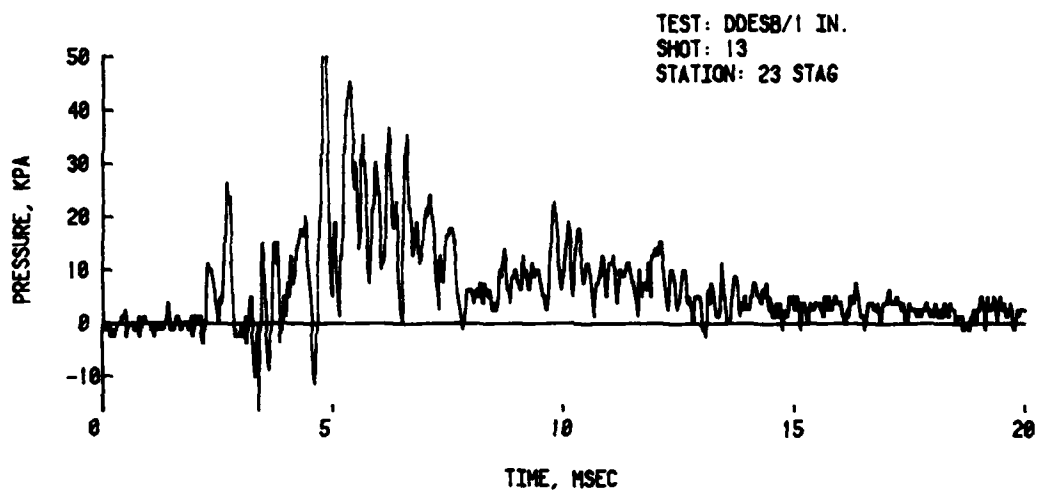
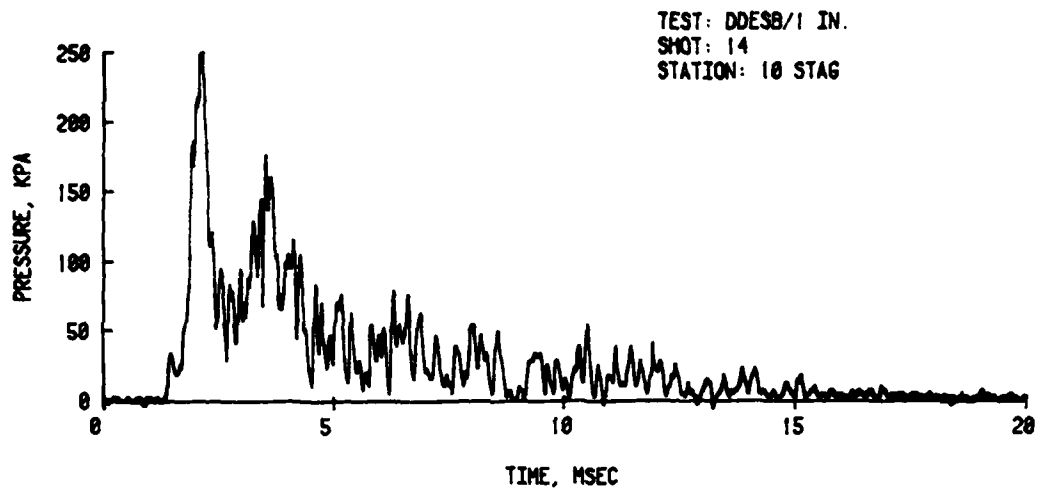
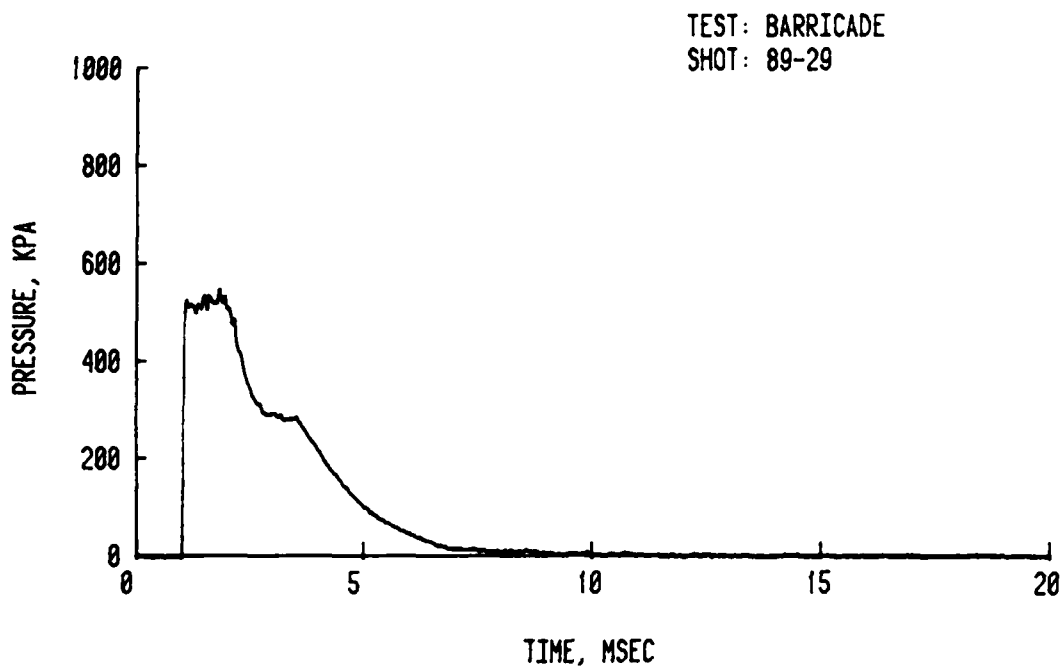
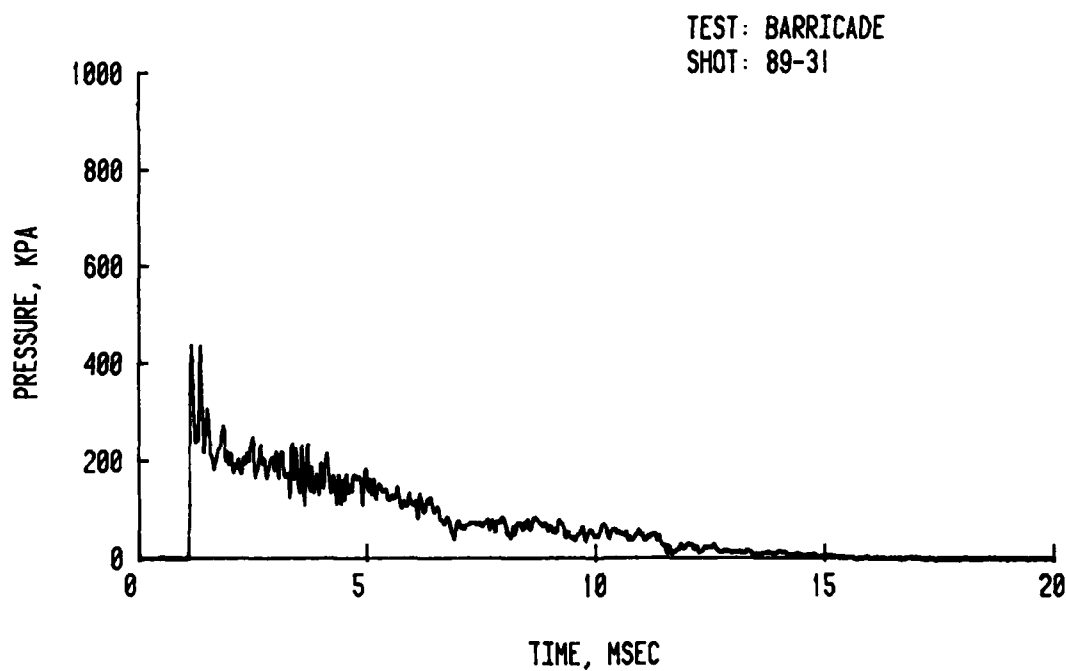


Figure 7b. Stagnation Pressure Traces, Without Barricade.



a. Exit Pressure.



b. Reflected Pressure.

Figure 8. Typical Pressure Traces at Exit and at Barricade Face.

3.2.2 Side-on Overpressures. The peak side-on overpressures (ΔP) recorded without barricade in place follow a predictable decay with distance along the 0° line. Table 1 lists values of ΔP [from Kingery and Gion (1989)], for the unbarricaded case, along with exit pressure (P_w), the pressure ratio, $\Delta P/P_w$, and predicted $\Delta P/P_w$ [using equation (1) from Skjeltrope, Heggdahl, and Jenssen (1977)]:

$$\Delta P/P_w = 1.24 (R/D_T)^{-1.35} . \quad (1)$$

Similar values are presented in Table 1 for the barricaded case.

Figure 9 shows plots of $\Delta P/P_w$ vs. R/D_T for the barricaded, unbarricaded, and calculated cases. Here it can be seen that the barricade tends to lower the side-on pressures at the 10 and 15 D stations, but at the 23 and 35 D stations, the values are larger. It is not known at present whether this increase at the 23 and 35 D stations is due to interactions of the flow with the barricade and the vertical walls leading from the tunnel or to other phenomena. The values are about 30% higher, which could affect the distance at which inhabited buildings could survive.

3.2.3 Stagnation Pressures. The stagnation overpressures from Kingery and Gion (1989), recorded along the 0° line without a barricade, are listed in Table 2 and plotted in Figure 10. It can be seen in Table 2 that the stagnation pressure created by the jet flow from the driver tube can range from two to eight times the side-on overpressure. In free-field blast, a peak side-on pressure of 27.6 kPa, as at station 10 say, should produce a stagnation pressure of 30.1 kPa, an increase of only about 9%. The stagnation pressure created by the jet flow was found to be 225.5 kPa, approximately 750% greater.

With barricade in place, stagnation pressures recorded along the 0° line show a dramatic decrease in levels. The recorded values are listed in Table 2 and plotted in Figure 10. The stagnation pressure and the side-on pressure are equal at 10 diameters, within reading error. This tells us that there is no jet flow enhancement at this station since the theoretical stagnation pressure should be 21 kPa, which is well within the error band of the instrumentation. Station 15 records a slight rise in stagnation pressure, indicating some flow enhancement, but there is a sharp decrease at the 23 and 35 D stations. We conclude that, with barricade in place, the jet flow effects have been greatly negated.

Table 1. Side-On Peak Overpressure vs. Distance Without and With a Barricade.

Distance, diameters	ΔP , kPa	P_w , kPa	Ratio, $\Delta P/P_w$	Predicted Ratio, $\Delta P/P_w$
Without Barricade				
10	27.6	503	0.0549	0.0554
15	15.9	503	0.0316	0.0320
23	9.0	503	0.0179	0.0180
35	4.8	503	0.0095	0.0102
With Barricade				
10	19.7	527	0.0374	0.0554
15	15.5	494	0.0314	0.0320
23	11.8	494	0.0239	0.0180
35	6.5	494	0.0132	0.0102

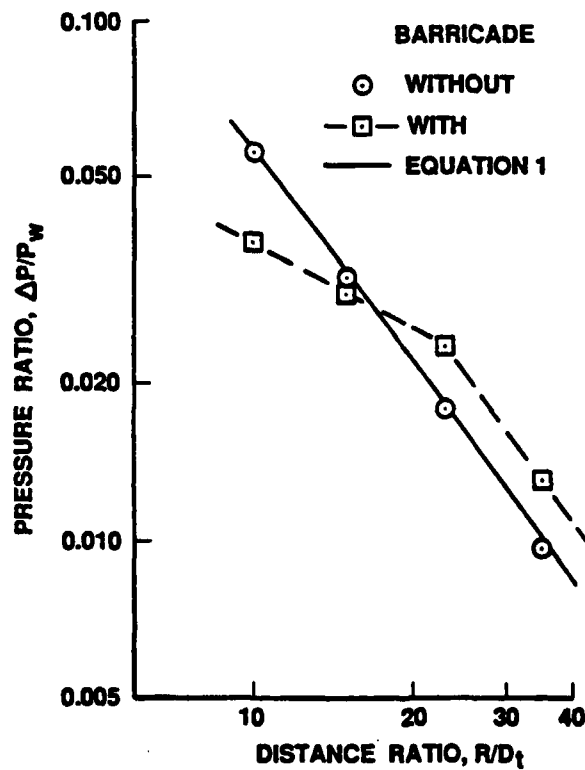


Figure 9. Pressure Ratios ($\Delta P/P_w$) vs. Distance Ratio (R/D_t) With and Without a Barricade.

Table 2. Stagnation Pressure vs. Distance Without and With a Barricade.

Distance, diameters	P_{STAG} , kPa	ΔP , kPa	Ratio $P_{STAG}/\Delta P$
Without Barricade			
10	225.5	27.6	8.2
15	100.0	15.9	6.3
23	50.3	9.0	5.6
35	10.3	4.8	2.1
With Barricade			
10	19.7	19.7	1.0
15	21.5	15.5	1.4
23	13.7	11.8	1.2
35	8.7	6.5	1.3

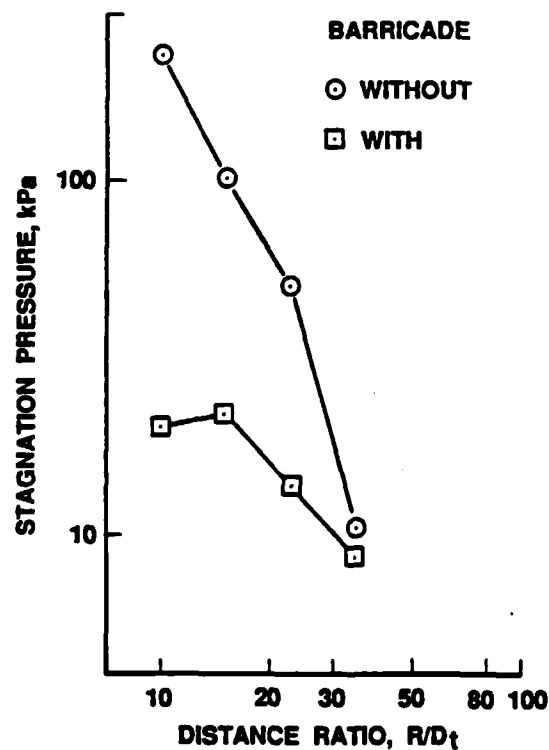


Figure 10. Stagnation Pressure (P_{STAG}) vs. Distance Ratio (R/D_t) With and Without a Barricade.

4. CONCLUSIONS

A model barricade built to about 1:140 scale of a barricade for some proposed Klotz tests (Vretblad 1988) has been exposed to the shock tube flow simulating an explosion in an explosives storage magazine. Only a single flow condition was attempted, a tube exit pressure (P_w) \approx 500 kPa (\approx 73 psi). Shadowgraphs and pressure measurements are exhibited. The results show that the barricade almost totally negates the jet flow enhancement of loadings along the 0° line. However, an increase of about 30% in side-on pressure level is noted at the inhabited building distance, which may be due to flow interactions with barricade and mountain side. This feature may merit consideration in the Q-D relationships.

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